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Engineering Note

Date: November 17. 1999
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Project: Central Fiber Tracker
Doc. No: A991117A

Subject: Bulk Power Supplies for the CFT Axial, Stereo and Preshower

Introduction

All Analog Front End boards of various types in the CFT system sit upon a cryostat mounted on the central platform. This cryostat is raised some 6.25 inches above the floor (the tiles, not the actual base) which allows mounting of the power supplies under the cryostat box. This document describes this system.

- The January 14, 2000 revision of this document added Figure 3, Tables 5 & 6, and notes on the rack monitors.
- On January 19, 2000 Figure 3, Tables 5 & 6 were updated based on new data regarding the cooling fans.
- On January 25, 2000 the nomenclature for AC phases was changed. Instead of referring to the three possible 208VAC connections in the three-phase circuit as 'X', 'Y' or 'Z' they are now referred to as 'A-B', 'B-C' and 'C-A', respectively, to insure that no confusion between 208 VAC wiring across phases and 115 VAC wiring from a single phase to the neutral exists.
- Typographical errors (115V line mis-labeled as 208V) fixed 2/2/2000.

Power Supplies Required

Each CFT Axial board requires approximately 42 Watts of power, utilizing five different voltages. A bulk supply of +5 volts and another of +3.3 volts are required to run the digital logic on the AFE. Analog circuitry requires ±12 Volts. The multi-chip module of the CFT system requires extremely quiet +5V, +5.2V and +3.5V power supplies, which are all locally generated by local linear regulation of a bulk +5.5V supply.

An analysis of the power supply load based upon the bill of materials for the 8-MCM AFE shows that the required currents for each of these voltages is as shown in Table 1.

Voltage	Current Required
+5 Volts	3.61 Amps
+5.5 Volts	1.2 Amps
±12 Volts	.45 Amps
+3.3 Volts	2.83 Amps

Table 1

A smaller number of 12-MCM AFE boards will be manufactured as well. These are expected to have larger current draw in the +5.5V, ±12V and +3.3V supplies, but about the same +5V load. Table 2 shows the expected current draws for the 12-MCM version.

Voltage	Current Required
+5 Volts	3.61 Amps
+5.5 Volts	1.8 Amps
±12 Volts	.675 Amps
+3.3 Volts	4.25 Amps

Table 2 – Current draw of one AFE

Power is distributed from the bulk supplies to backplanes. Each backplane services eight AFE boards (either size). The way the cassettes of the cryostat are organized, in any group of eight there will be no more than four of the 12-MCM AFE boards. A moment's multiplication then gives the total amount of current per backplane expected, given in Table 3. With a largest current of some 30 Amps, the largest wire gauge expected is #10 or #8, still reasonably flexible.

Voltage	**Current of four 8-MCM AFE**	**Current of four 12-MCM AFE**	**Total Current**
+5 Volts	3.61 * 4 = 14.44 Amps	3.61 * 4 = 14.44 Amps	28.88 Amps
+5.5 Volts	1.2 * 4 = 4.8 Amps	1.8 * 4 = 7.2 Amps	12.0 Amps
±12 Volts	.45 * 4 = 1.8 Amps	.675 * 4 = 2.5 Amps	4.3 Amps
+3.3 Volts	2.83 * 4 = 11.32 Amps	4.25 * 4 = 17 Amps	28.32 Amps

Table 3 – Current Draw per AFE Backplane

To determine the power supply current, a safety factor of some 30% is applied to these maximum currents, which gives the power supply requirements of Table 4. These values are 1.3 times the values of Table 3, rounded up.

Voltage	**Current Required**	**Wattage**
+5 Volts	40 Amps	200 W
+5.5 Volts	20 Amps	110 W
±12 Volts	6 Amps	144 W
+3.3 Volts	40 Amps	132 W
	TOTAL =>	586 W

Table 4 – Total Wattage per AFE Backplane

Power Supply Selection

The Vicor MegaPac PFC supply provides a chassis with room for eight output modules and a total power rating of 1200 – 1600 Watts (dependent upon input AC voltage). At 115 VAC single-phase, the device is rated at 1200W total output and with higher input voltage (e.g. 220 VAC) up to 1600W can be drawn. Figure 1 shows a sketch of the Vicor device, where all eight slots are used to drive the power to two backplanes.

POWER MODULES

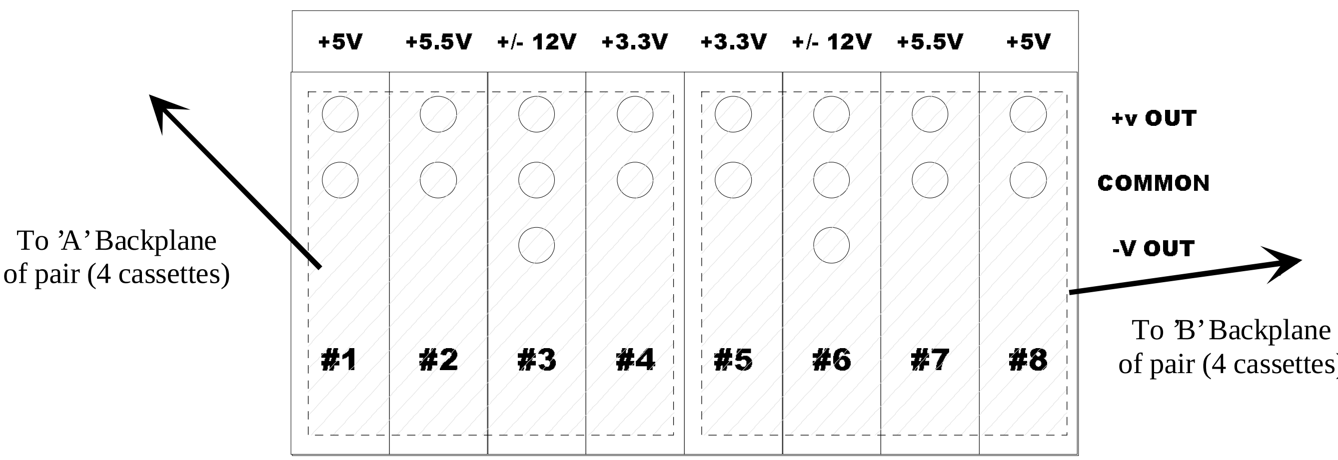
#1 +5V @ 40A 200 WATTS
#2 +5.5V @ 20A 110 WATTS
#3 +/-12V @ 6A 144 WATTS
#4 +3.3V @ 40A 132 WATTS
#5 +3.3V @ 40A 132 WATTS
#6 +/-12V @ 6A 144 WATTS
#7 +5.5V @ 20A 110 WATTS
#8 +5V @ 40A 200 WATTS

TOTAL 1176 WATTS

Each Vicor Mega-Pac supplies power for 8 cassettes. Twelve Mega-Pacs supply all the power for the internal 96 cassettes of the CFT system. The four cassettes at each end of the cryostat are each powered by a separate Mega-Pac which is only 1/2 loaded.

Analog Front End
Bulk Power Distribution

J. T. Anderson 11/17/99



VICOR MEGA-PAC PFC (1200W)

Figure 1

Mechanically, each of the Vicor power supplies is assumed to rest in a box which is mounted under the cryostat itself, as sketched in Figure 2. The box hangs from the bottom plate of the cryostat with a flexed top so that any condensation from the cryostat is directed away from the electronics. Sufficient room is present to put a voltage/current monitor board (for example, Dave Huffman's design) in the same box as the power supply, plus also a fuse panel for all the wires that run from the supplies up to the AFE backplanes.

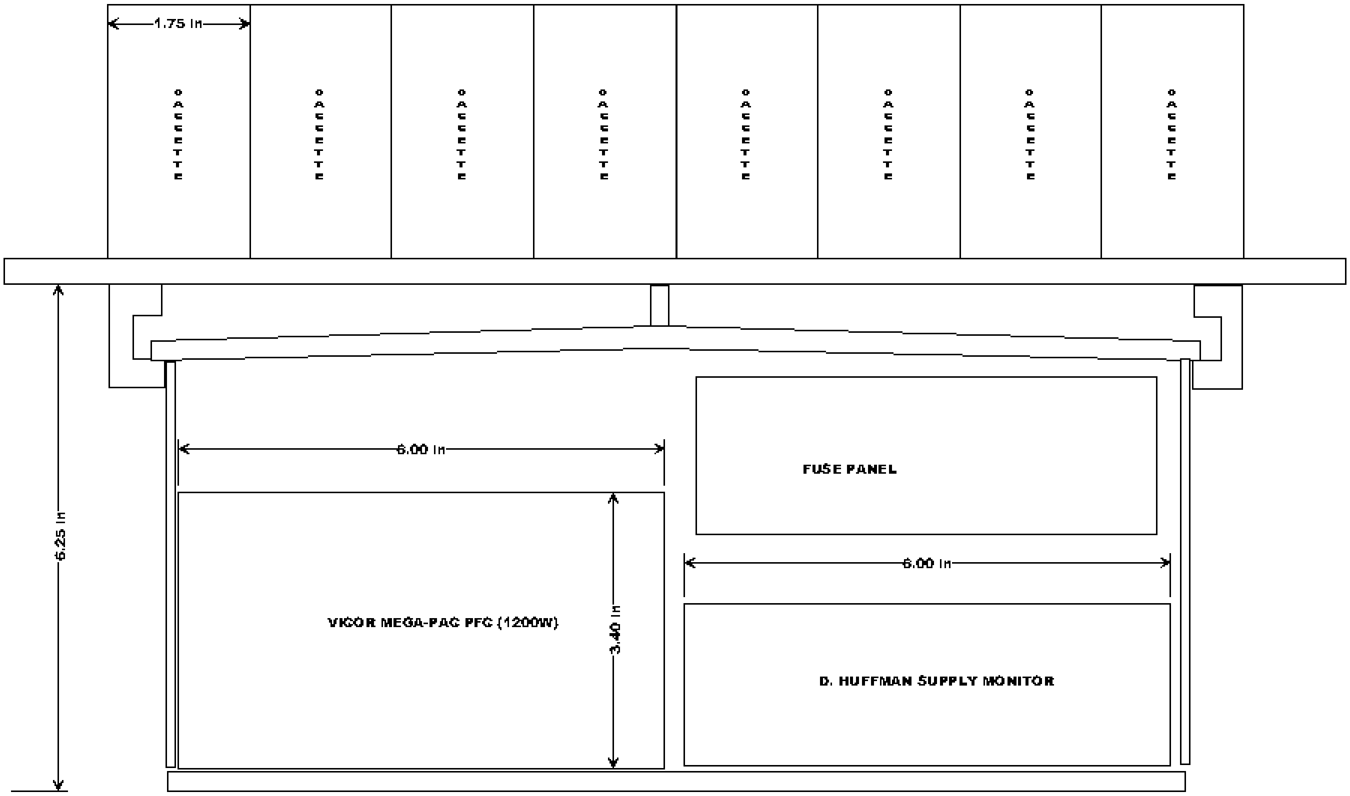


Figure 2

AC Distribution Considerations

Given that there are some 200 AFE boards in the cryostat and each Vicor box can drive sixteen of them, about a dozen Vicor boxes are required. However, the mechanics of the cryostat break it into two halves such that each side of the cryostat requires six and one half Vicor power supplies. This will be accomodated by having six fully loaded Vicor boxes on each side of the cryostat and a half-loaded supply at each end, for a total of thirteen. Three-phase power will be brought into the area with two fully-loaded Vicor boxes per phase. The two half-loaded boxes will be on one phase each and the required monitoring electronics run off the third phase. Figure 3 shows the layout.

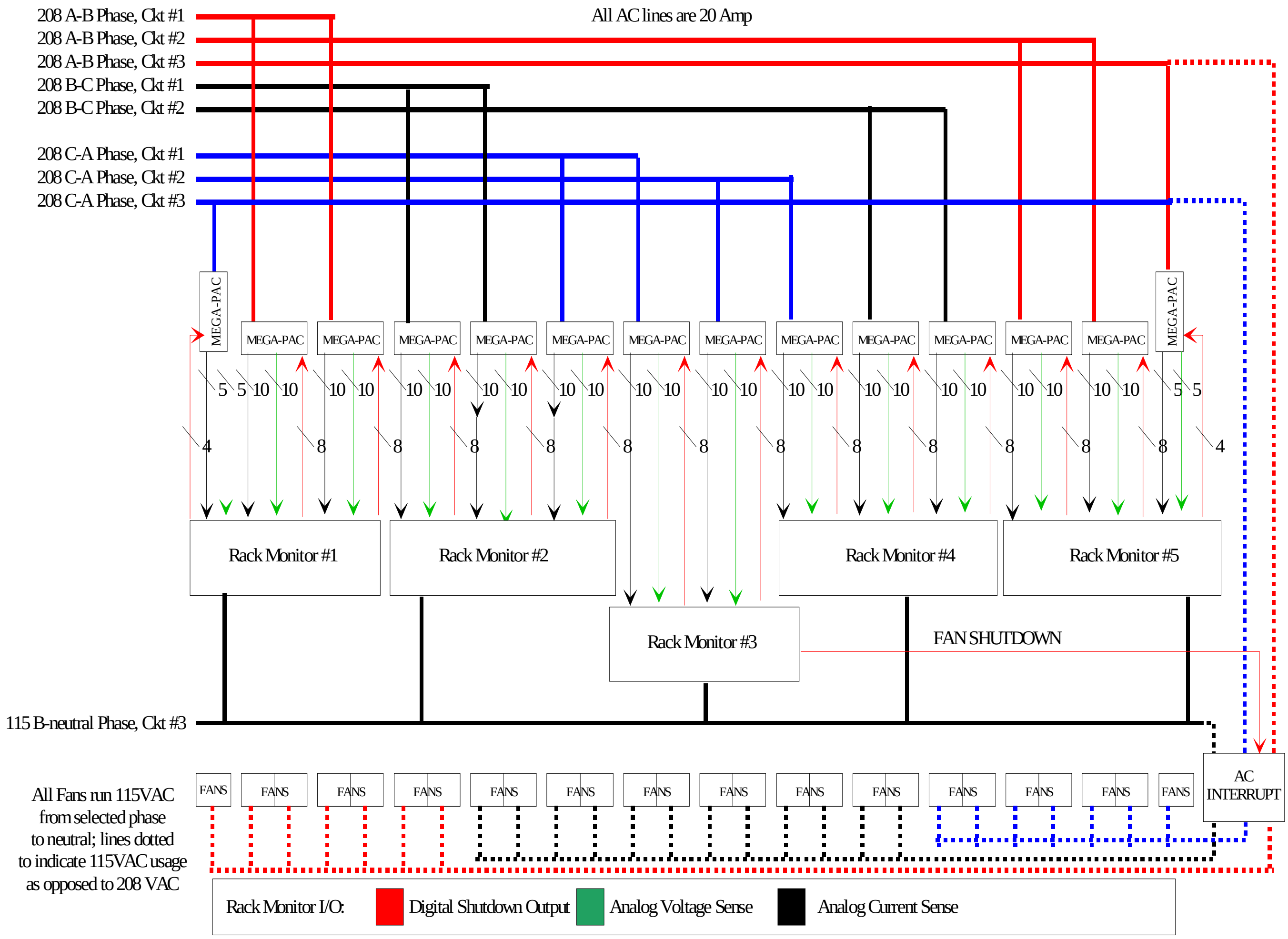


Figure 3

A total of three 208VAC, 20 Amp, three phase lines are run throughout the system. Each Vicor power supply drives two backplanes, and in most cases, each AC phase drives two Vicor power supplies. Thus, on average, each phase must be capable of supplying four times the power listed in Table 4 above. Table 5 breaks down each of the nine 208VAC lines for total power analysis. Table 6 provides the breakout of expected neutral currents for each of the three AC distributions.

Rack monitors and fans for the system run at 115V and are scattered around the three phases (A-neutral, circuit #3, B-neutral, circuit #3 and C-neutral, circuit #3) to distribute the load and minimize the peak neutral current.

AC Main	Expected Max Load (watts)	Efficiency (rated/used)	Power Factor (rated/used)	AC Wattage Load (max load at min. eff.)	Max load in Amps for V=208 VAC	80% of breaker size
A-B, circuit #1	586W * 4 = 2344 W	80%/75%[1]	(99% - 95%), used 95%[2]	3289 W[3]	15.82 A [4]	16A
A-B, circuit #2	586W * 4 = 2344 W	80%/75%	(99% - 95%), used 95%	3289 W	15.82 A	16A
A-B, circuit #3 P/S	(586W / 2) = 293 W	80%/75%[5]	(99% - 95%), used 95%	411 W	1.97 A	16 A
A-neutral, circuit #3 FANS[6]	10 * 35W = 350 W	100%	100%	350 W	3.04 A (fans are 115 VAC)	16 A
B-C, circuit #1	586W * 4 = 2344 W	80%/75%	(99% - 95%), used 95%	3289 W	15.82 A	16A
B-C, circuit #2	586W * 4 = 2344 W	80%/75%	(99% - 95%), used 95%	3289 W	15.82 A	16A
B-neutral, circuit #3 Rack Monitors	(5 * 30W) = 150 W	N/A (used 100%)	N/A (used 100%)	150 W	1.30 A (115 VAC)	16 A
B-neutral, circuit #3 FANS	6 * 35W = 210 W	100%	100%	210 W	1.83 A (fans are 115 VAC)	16 A
C-A, circuit #1	586W * 4 = 2344 W	80%/75%	(99% - 95%), used 95%	3289 W	15.82 A	16A
C-A, circuit #2	586W * 4 = 2344 W	80%/75%	(99% - 95%), used 95%	3289 W	15.82 A	16A
C-A, circuit #3 P/S	(586W / 2) = 293 W	80%/75%[7]	(99% - 95%), used 95%	411 W	1.97 A	16 A
C-neutral, circuit #3 FANS	10 * 35W = 350 W	100%	100%	350 W	3.04 A (fans are 115 VAC)	16 A

Table 5 – AC Mains Analysis

[1] Vicor states a typical efficiency of 80% for all modules. 75% is used here to add some margin.

[2] Vicor specifies 99% PF at 115VAC, derated to 95% at 220VAC.

[3] Simplistically calculated as (max load) * (1/eff) * (1/pf) = 1.587 * max load.

[4] Since the power factor has already been built in, this is just max wattage load divided by 208.

[5] Efficiency and power factor only applied to power supply portion, not to fan portion.

[6] The 26 fans needed to cool the system (13 per cryostat) are broken up into sets of 10,3,3,10 with 10, 6 and 10 on each phase of the power. The fans are rated at 31 Watts each according to Dan Olis; a working number of 35 Watts each is used.

[7] Efficiency and power factor only applied to power supply portion, not to fan portion.

Calculation of the neutral current in circuit #3, where there is a mix of 208 VAC and 115 VAC, gets a little tricky. The presumption here is that the A-B phase power supplies are wired 208 VAC between phases A-B and B-C, and that the C-A phase power supplies are wired 208 VAC between phases C-A and A-B. Since the two 208 VAC loads are the same, and all the fan and rack monitor loads are wired Y-configuration to the neutral, the phase imbalance in the B-C phase (phase difference of the current with respect to the voltage in the B-C) should be equal and opposite to that applied to the C-A phase. This will result in no net neutral current due to the 208 VAC loads and so long as the B-C-configuration 115 VAC loads are all relatively balanced the neutral current should be small. This is, of course, all assuming that there's no other imbalances due to the different loads; the fans are impedance controlled but some power factor may yet be present.

Circuit	**A-B phase current**	**B-C phase current**	**C-A phase current**	**Max Neutral Current**
1	15.82 A	15.82 A	15.82 A	Balanced load
2	15.82 A	15.82 A	15.82 A	Balanced load
3 (P/S)	1.97 A	0	1.97 A	0, but phase imbalance.
Circuit	**A-neutral phase current**	**B-neutral phase current**	**C-neutral phase current**	**Max Neutral Current**
3 (Fans and monitors)	3.04 A	3.13 A	3.04 A	Est. 180 mA

Table 6 – Neutral Current Analysis

Having not calculated an unbalanced 3-phase system in a few years, I'm going to cheat and let the computer do the work for me. A simple SPICE schematic suffices to estimate how the system works as shown in Figure 4. Lacking any better knowledge for power factor, I just use simple resistances where the resistance in each case is determined from the power in the preceding tables and the RMS voltages of the various sources. Each of the three sources is a simple sine source of amplitude √2 * the RMS voltage (115 VAC).

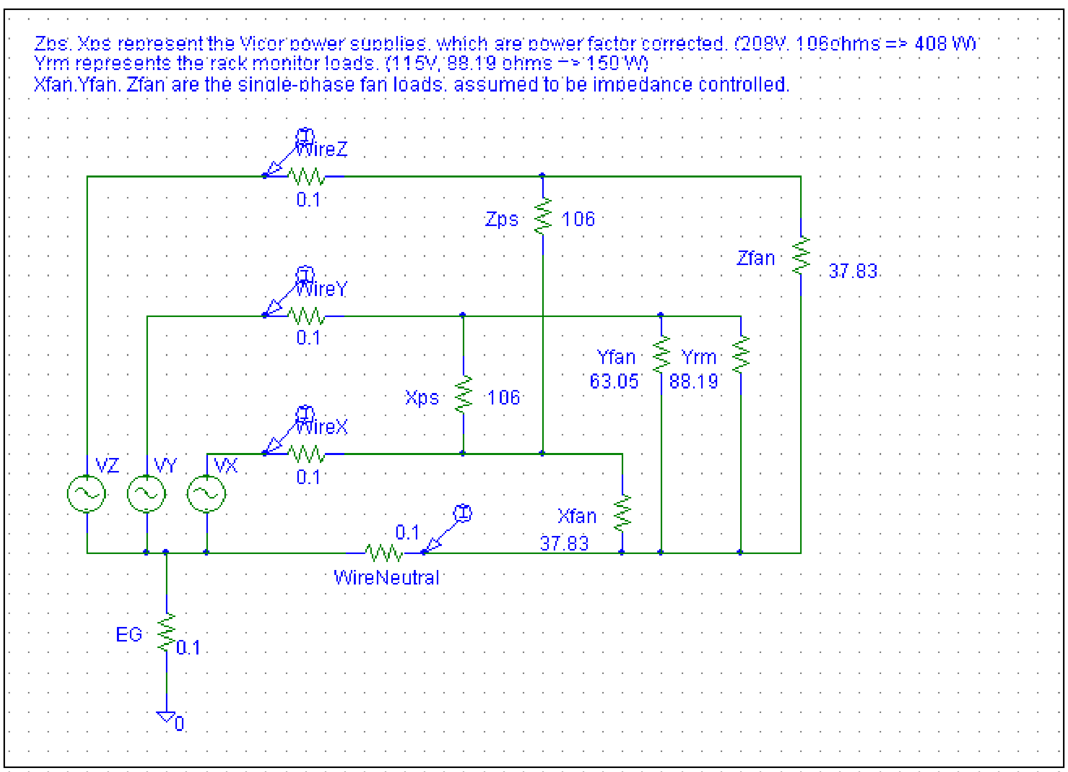


Figure 4

Small resistors model the wire resistances and provide handy spots to hide a current probe. A quick run through transient analysis, and here's what you get:

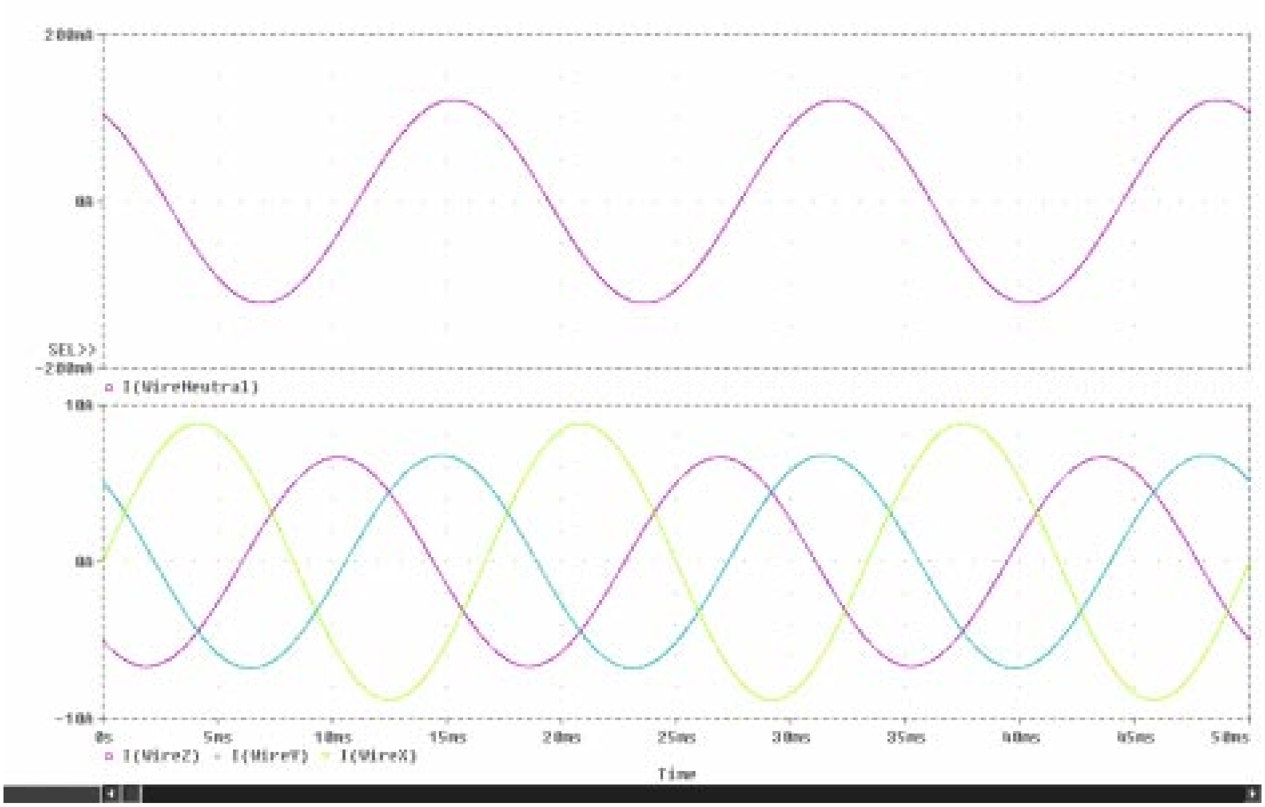


Figure 5

The neutral current is pretty darn close to that estimated above, and there's a little phase shift in the currents, but not too horrible. A run with the cursors gives approximate phase values as follows:

- Current in A-B with respect to current in C-A: 128 degrees (8 degrees off, or a power factor of 99%)
- Current in C-A with respect to current in B-C: 100 degrees (-20 degrees off, or a power factor of 93.9%)
- Current in B-C with respect to current in A-B: 132 degrees (12 degrees off, or a power factor of 97.8%)

Details of AC Distribution

All AC power is expected to come to the central platform from a master distribution panel located on the west platform. The AC interrupt for the fan power is also assumed to be mounted on the west panel. Numerous AC interrupters alre already present in the racks on the west side; if free channels are available they will be used. Twenty-eight duplex outlets are required to accommodate the connections, and are mounted underneath the cryostat. These 28 are spaced equally as fourteen pairs along the length of the cryostat and are mounted to the south face of the I-beam that runs under the north face of the cryostat, as shown in Figure 4. In addition to the 14 double duplex outlets under the cryostat, an additional two double duplex outlets (#15 and #16) must be mounted near the racks where the Rack Monitors are located. The exact details of each duplex outlet are described in Table 7. A sketch of the positions and phases is given as Figure 6.[8]

Although 14 double-duplex boxes could be used, since different phases of different circuits are being routed to each duplex outlet in a pair, each duplex outlet should be in its own box to conform to Fermilab safety labeling requirements. To conserve some paper, Table 7 shows each pair of duplex outlets per row; interpret the first column as one single junction box and the second column as the other single junction box of the pair.

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[8] There is no absolute requirement that duplex outlets be used. For instance, the fans and/or the rack monitors could be run using Panduit stips just as well.

Duplex Outlet Pair Number	Usage of left duplex outlet of pair	Usage of right duplex outlet of pair
1A, 1B (Westernmost)	Interruptable A-neutral phase, three-phase circuit #3 power for fans; standard 115 VAC 15A outlet.	C-A phase, three-phase circuit #3 power for end Vicor power supply; 208V, 10A outlet.
2A, 2B	Interruptable A-neutral phase, three-phase circuit #3 power for fans; standard 115 VAC 15A outlet.	A-B phase, three-phase circuit #1 power for Vicor power supply; 208V, 10A outlet.
3A. 3B	Interruptable A-neutral phase, three-phase circuit #3 power for fans; standard 115 VAC 15A outlet.	A-B phase, three-phase circuit #1 power for Vicor power supply; 208V, 10A outlet.
4A, 4B	Interruptable A-neutral phase, three-phase circuit #3 power for fans; standard 115 VAC 15A outlet.	B-C phase, three-phase circuit #1 power for Vicor power supply; 208V, 10A outlet.
5A, 5B	Interruptable A-neutral phase, three-phase circuit #3 power for fans; standard 115 VAC 15A outlet.	B-C phase, three-phase circuit #1 power for Vicor power supply; 208V, 10A outlet.
6A, 6B	Interruptable B-neutral phase, three-phase circuit #3 power for fans; standard 115 VAC 15A outlet.	C-A phase, three-phase circuit #1 power for Vicor power supply; 208V, 10A outlet.
7A, 7B (Central)	Interruptable B-neutral phase, three-phase circuit #3 power for fans; standard 115 VAC 15A outlet.	C-A phase, three-phase circuit #1 power for Vicor power supply; 208V, 10A outlet.
8A, 8B (Central)	Interruptable B-neutral phase, three-phase circuit #3 power for fans; standard 115 VAC 15A outlet.	C-A phase, three-phase circuit #2 power for Vicor power supply; 208V, 10A outlet.
9A, 9B	Interruptable B-neutral phase, three-phase circuit #3 power for fans; standard 115 VAC 15A outlet.	C-A phase, three-phase circuit #2 power for Vicor power supply; 208V, 10A outlet.
10A, 10B	Interruptable C-neutral phase, three-phase circuit #3 power for fans; standard 115 VAC 15A outlet.	B-C phase, three-phase circuit #2 power for Vicor power supply; 208V, 10A outlet.
11A, 11B	Interruptable C-neutral phase, three-phase circuit #3 power for fans; standard 115 VAC 15A outlet.	B-C phase, three-phase circuit #2 power for Vicor power supply; 208V, 10A outlet.
12A, 12B	Interruptable C-neutral phase, three-phase circuit #3 power for fans; standard 115 VAC 15A outlet.	A-B phase, three-phase circuit #2 power for Vicor power supply; 208V, 10A outlet.
13A, 13B	Interruptable C-neutral phase, three-phase circuit #3 power for fans; standard 115 VAC 15A outlet.	A-B phase, three-phase circuit #2 power for Vicor power supply; 208V, 10A outlet.
14 A, 14B (Easternmost)	Interruptable C-neutral phase, three-phase circuit #3 power for fans; standard 115 VAC 15A outlet.	A-B phase, three-phase circuit #3 power for end Vicor power supply; 208V, 10A outlet.
Double Duplex Outlet Number	**Usage of left duplex outlet of double**	**Usage of right duplex outlet of double**
15 (center north rack)	Interruptable B-neutral phase, three-phase circuit #3 power for fans and/or Rack Monitors; standard 115 VAC 15A outlet.	Interruptable B-neutral phase, three-phase circuit #3 power for fans and/or Rack Monitors; standard 115 VAC 15A outlet.
16 (center north rack)	Interruptable B-neutral phase, three-phase circuit #3 power for fans and/or Rack Monitors; standard 115 VAC 15A outlet.	Interruptable B-neutral phase, three-phase circuit #3 power for fans and/or Rack Monitors; standard 115 VAC 15A outlet.

Table 7

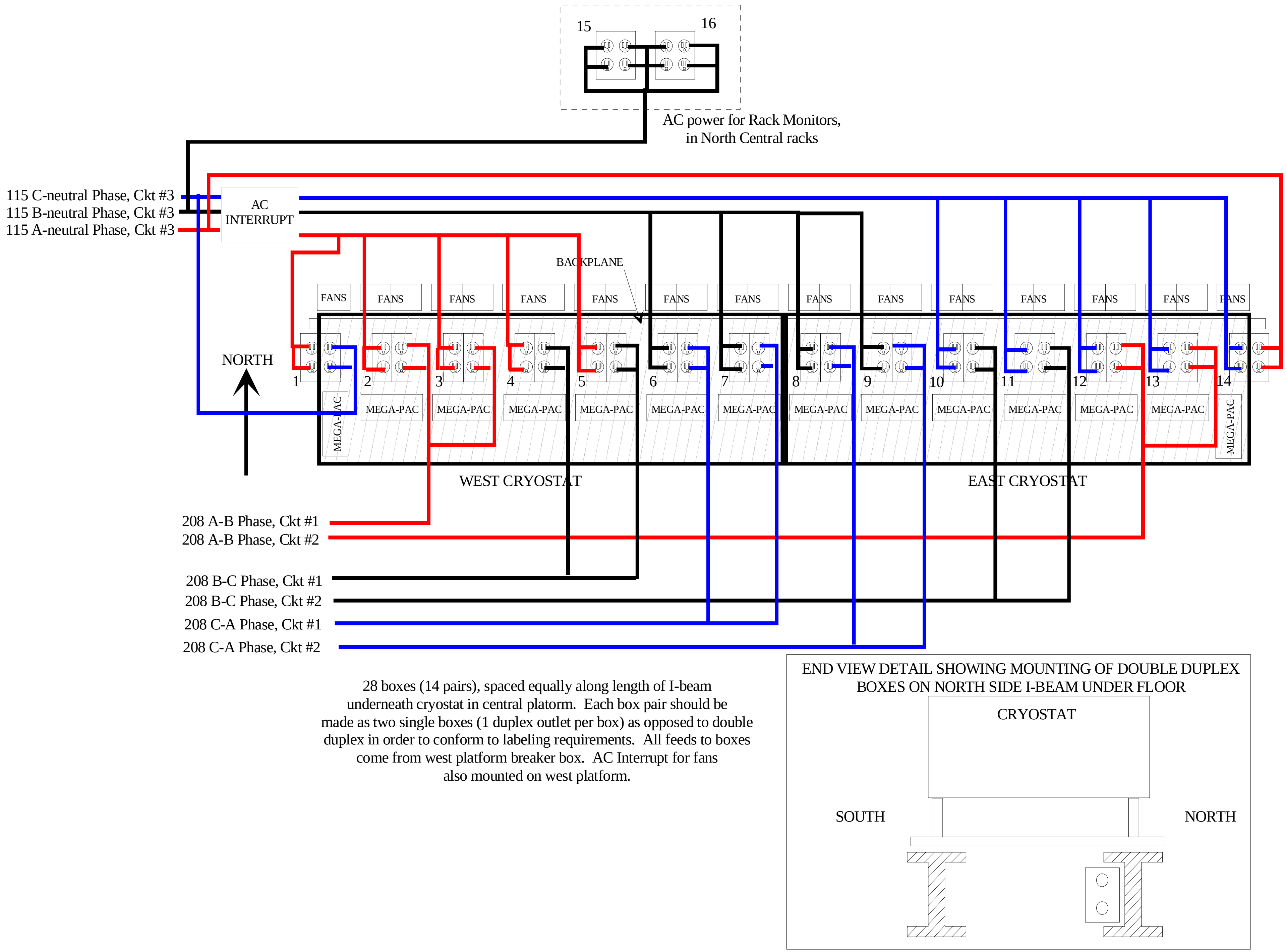
15
16
AC power for Rack Monitors,
in North Central racks
115 C-neutral Phase, Ckt #3
115 B-neutral Phase, Ckt #3
115 A-neutral Phase, Ckt #3
AC INTERRUPT
BACKPLANE
FANS
NORTH
1 2 3 4 5 6 7 8 9 10 11 12 13 14
MEGA-PAC
WEST CRYOSTAT
EAST CRYOSTAT
208 A-B Phase, Ckt #1
208 A-B Phase, Ckt #2
208 B-C Phase, Ckt #1
208 B-C Phase, Ckt #2
208 C-A Phase, Ckt #1
208 C-A Phase, Ckt #2
28 boxes (14 pairs), spaced equally along length of I-beam underneath cryostat in central platorm. Each box pair should be made as two single boxes (1 duplex outlet per box) as opposed to double duplex in order to conform to labeling requirements. All feeds to boxes come from west platform breaker box. AC Interrupt for fans also mounted on west platform.
END VIEW DETAIL SHOWING MOUNTING OF DOUBLE DUPLEX BOXES ON NORTH SIDE I-BEAM UNDER FLOOR
CRYOSTAT
SOUTH
NORTH

Figure 6

Cooling and Airflow

The Vicor supplies are forced air cooled using an internal fan. The depth of the power supply box shown in Figure 2 is quite a bit shorter than the width of the cryostat, providing ample room to place a heat exchanger at the intake (rear) side of the power supply. Space for filters is also available. The orientation of the system will be such that the intake of the airflow is at the 'front', or north, side of the cryostat, with the exhaust at the south, or backplane side. This is the same side as the wires are run. An alternate possibility, which will be dependent upon how much interference occurs from cables, is to mount the Vicor supplies in less-wide but more-deep boxes such that the airflow in all cases runs west-to-east. In this scenario the heat exchangers would be mounted between the power supply boxes such that the whole stack pumps west-to-east.

Protection of Equipment

The filter/heat exchanger assembly at floor level will have to be protected from physical damage by a screen. Since the power supplies are at floor level, toes and shoes will find them often. At the rear side, a plexiglas plate with exhaust holes will provide air exhaust at the power supply side, routing holes to pass the cable assemblies and a solid area to protect the monitor and fuseblock areas. Use of plexiglas will allow visual inspection of indicator lights and fuses.

Monitoring and System Control

Five rack monitors as shown in Figure 3 suffice for monitoring the entire system. Each rack monitor is capable of 64 analog inputs, 8 analog outputs and 64 digital I/O lines. Each Vicor power supply is expected to yield an analog measurement of output voltage and an analog measurement of current drawn. In addition, each output spigot of each Vicor supply may be individually shut down via a digital control. Sufficient digital I/O lines are present in the rack monitors as shown to provide a redundant global shutdown digital output for each Vicor supply. At present no use is planned for the analog outputs of the rack monitors.

Each backplane of the AFE system – which connects eight boards together – also provides the physical connection to the 1553 control bus. The 1553 addressing scheme can handle up to 31 Remote Terminals on a given link. There are 26 backplanes in the AFE system, so the Rack Monitors could actually be added to the backplanes to form one big 1553 bus for the whole AFE system, if the AFE 1553 interfaces were designed such that the board position was used to address which pair of subaddresses the AFE responded to. This would, however, require new logic design in the AFEs. A more probable scheme uses multiple 1553 links for all the backplanes, and one more 1553 line for the five Rack Monitors. In this more plausible case each backplane is eight Remote Terminals, so each 1553 interface module (two links) can support up to six backplanes. A total of nine 1553 links (five 1553 interface boards) wouls be required for the whole system.

Table 7 gives the breakout, by Rack Monitor, of how many channels of input and output are used up by the monitoring scheme implied in Figure 3. More than sufficient input channels remain to implement whatever forms of temperature, smoke and drip detection are deemed necessary.

Rack Monitor	**Analog Inputs Used**	**Digital I/O used**	**Analog Outputs Used**	**Available Analog Inputs**	**Available Digital I/O**	**Available Analog Outputs**
1	50	20	0	14	44	8
2	60	24	0	4	40	8
3	40	17	0	24	47	8
4	60	24	0	4	40	8
5	50	20	0	14	44	8

Table 8

In the case of Rack Monitor #3, one digital output is assumed to be used to control an interlock input to an AC distribution box which will be used to shut down the fans in case of smoke. This distribution box will have to be mounted in a rack, presumably on the west platform. Since only a few amps are required it may be possible to find an unused channel of such a box already mounted there. The Rack monitors themselves are intended to be mounted in the North racks of the central platform.